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AN EXPERIMENTAL INVESTIGATION ON DIESEL ENGINE PERFORMANCE USING MORINGA OLIFERA BIODIESEL WITH THE EFFECT OF DIFFERENT INJECTION PRESSURES

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ABSTRACT

Increasing cost of petroleum diesel and environmental degradation due to automotive pollution, forces the researchers to search an alternate fuel like biofuel and biodiesel for diesel engine. The biodiesel is produced from Moringa oil by tranesterification process. In the present work, test was conducted to study the performance, emission and combustion characteristics of a diesel engine using Moringa oleifera oil methyl ester- diesel blend (B25: 25%MOME + 75% Diesel) with different injection pressures like 200bar (original), 220bar, 240 and 260 bar at different operating conditions. The results revealed that the Brake thermal efficiency, brake specific fuel consumption were calculated and the emissions parameters like Carbon monoxide, unburnt hydro carbon, Nitrogen oxide and Smoke opacity were and analyzed and compared with standard diesel.

KEYWORDS: Diesel Engine, Performance, Emission, Moringa Oleifera Biodiesel & Combustion

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Original Article

INTRODUCTION

Compression ignition engine played an important role in power plants, agricultural and automotive transportation and defense sectors due to its low fuel economy and less emissions except NOx and Particulates emissions. On the other hand, the petroleum fuel is limited and depleting by day as its increase in usage very rapidly and environmental degradation. The fast depletion of fossil fuel resources and steep increase in energy consumption have created the awareness among the researchers to research for substitutes for petroleum fuels. Hence, developing alternative for diesel for efficient and clean application in the diesel engine (Hüseyin Aydina and Cumali Ilkiliç 2017). Vegetable oil is an attractive alternate fuel for diesel engines due to its properties are comparable with diesel and its biodegradability and renewable in nature.

Agarwal and Atul Dhar (2013) investigated the engine performance characteristics using Karanja oil blends with diesel and found that the Smoke emissions were found to be decreased for 20-50% (v/v) Karanja oil fuel blends and the exhaust gas emissions like CO and HC are increased for higher Karanja oil blends when compared to diesel. Venkanna and Venkataraman Reddy (2015) has examined the diesel engines performance and emission using Honne oil and its blends like H10 and H20 as an alternative fuel. At lower loads, BSEC of diesel engine with H10 and H20 are comparable with neat diesel. The CO and Smoke opacity emissions for H10 and H20 were decreased for all loads and NOx emissions of H10 to H50 were decreased when compared with diesel. Biodiesel is one of the best alternatives for diesel fuel and can reduce the dependency of fossil-based diesel fuels

and environmental pollutants without requiring any modifications of the engine. It is non-explosive, non-flammable, non-toxic, renewable, biodegradable (Amani et al., 2013; Thomas et al., 2013).

Biodiesel can be produced by the chemical process by transesterification using vegetable oils and animal fats. Biodiesel gives slightly lower BTE and slightly lower emissions like CO and smoke (Ozener et al. 2014). Anand et al (2011) carried out the experiment on a turbocharged, truck diesel engine using Karanji biodiesel-methanol diesel blend. The BTE for biodiesel blends increased about 4.2% and CO and NOx emissions decreased by about 46% and 37.3% respectively at 80% of the load. However, the peak pressure and the peak energy release rate decreases significantly at higher load conditions. Nagaraju et al. (2008) determined the effect of using B20 in a diesel engine combustion, performance and exhaust emissions in a CI engine. The results of the experiments revealed that the exhaust emissions were lower than that of diesel, while BSFC was increased for B20 when compared with diesel fuel.

Hüseyin Aydin and Hasan Bayindir (2017) investigated the performance and emissions of cottonseed oil methyl ester in a diesel engine using different blends of cotton seed oil methyl etser. The results showed that the use of the lower blends (B5) slightly increases the engine torque at medium and higher speeds and there were no significant differences in performance values of B5, B20 and diesel fuel. The exhaust emissions were reduced significantly for biodiesel blends when compared to diesel. Hasanserin & Akar (2014) carried out an experiment in a diesel engine operated with tea seed (Camellia sinensis) oil biodiesel blends. The results indicated that there is a decrease in power output with the increase in biodiesel content in the mixture. Specific Fuel Consumption (SFC) was increased with increase in blends. The CO and HC emissions were reduced; NOx emissions were increased with increasing biodiesel contents in the mixture. It is suggested that, up to 20% volumetric content of tea seed biodiesel could be effectively used in fuel mixture, serving the purpose of reduction in diesel fuel usage.

Mofijur (2014) have tested the performance of a diesel engine with 5% and 10% Moringa and Palm biodiesel blends with diesel. The results indicated that the 5% both the fuel blends produced slightly lower brake powers and higher brake specific fuel consumption when compared to diesel fuel over the entire range of speeds. The average emissions of CO and HC were slightly increased the NOx when compared with diesel fuel for both the fuel blends. Kaushal Kumar and Sharma (2016) conducted the performance and emission characteristics of diesel engine using Jatropha, Moringa and Palm biodiesel blends. It is found that the biodiesel blends decreases the brake power and increases the BSFC when compared to diesel. The CO and HC emissions were decreased but the NOx emissions were increased when compared with diesel. Mofijur et al (2014) tested the engine performance using Moringa biodiesel blends (B10 and B20) at various speeds. The brake power was decreased for B10 and B20 and increased brake specific fuel consumption when compared with diesel. The CO and HC emissions were decreased for B10 and B20 fuels but slightly increased NO emission when compared with diesel.

Fuel injection pressure plays an important role in diesel engine performance. The higher injection pressure decreases the fuel droplets size which aids in better formation and mixing of fuel to air during ignition period, resulting in increase in performance. High-pressure injection in combination with small orifice can achieve lean combustion which allows better fuel atomization, evaporation and improved emissions and also reduced the soot emissions (Prashanth Karra and Song Charng Kong 2008; Sukumar Puhan et al.2009). Rajan et al. (2019) reported that the effect of injection pressure on the emission characteristics of a diesel engine using diesel and biodiesel blends. The BTE, EGT, NO, emissions were increased and BSFC, CO. HC and smoke emissions decreased with the increase in injection pressure from 200-260 bar.

They found that the optimum injection pressure was 240 bar. The authors (Pandian et al.(2011); Sanjay Patil and Akarte (2012); Purushotham Nayak, and Sreekantha (2014)) also found that effect of injection pressure on the emission characteristics of a diesel engine using biodiesel blends with diesel and reported that CO, HC and smoke emissions reduced but the NO emissions increased with injection pressure at full load.

Performance and emission characteristics of diesel engine using 25% biodiesel mix by varying the IP. Emissions of carbon monoxide, hydrocarbon and smoke have been reduced and emissions of NOx have been increased by increasing the IP at full load (Jindal et al 2010; Senthil kumar et al 2016; Ravichandran et al 2017). Donepudi Jagadish (2017) tested the causes 180, 220 and 260bar NOPs on the performance of a diesel engine using biodiesel mixtures. BTE has been increased with a decrease in BSFC for the increase in FIPs and NOx emissions have been increased with an increase in FIPs. Arunprasad and Balusamy (2018) studied the influence of IP and IT on the performance and emission of diesel engines by using mixed biodiesel blends. The results revealed that the BTE was increased by 2.4% with an increase in IP and 1.5% with an advancing the IT for full load, and it is lesser than diesel. The emissions of HC, CO and smoke for 230 bar IP and 27° bTDC IT are decreasing and the emissions of NOx and CO2 are significantly increased by increasing IP and IT.

Jiaqiang et al (2018) evaluated the effect performance of a diesel engine with fish oil methyl ester blends with the causes of IP and IT. BSFC and NOx emissions have been shown to increase along with a reduction in soot, HC and CO emissions as the percentage of biodiesel increases with increase in IP and IT. Akash Deep et al (2017) examined the effects of varying ITs and IPs on a diesel engine fuelled with 20% blend of castor biodiesel. The retarded injection time has been reported to reduce the peak cylinder pressure and decrease in BTE. At the original injection time of 23°bTDC at 200bar, the CO and HC emissions were found to be decreased. Harun Kumar et al (2018) have tested the effects of varying ITs on a diesel engine fuelled with 20%blend of tamarind seed biodiesel. BTE has improved by 3.18% compared to standard IT with a significant reduction in CO, HC, NOx and smoke emissions. The aim of the present work is to investigate the effect of 25%MOME blends on the engine performance and emission parameters and the in-cylinder pressure at different engine operating conditions with different injection pressures and the results were compared to diesel.

MATERIALS AND METHODS

Moringa Oleifera Methyl Ester (MOME)

Moringa oleifera is an evergreen plant, fast growing and draught resistant tree and widely cultivated in tropical and subtropical areas in dry sandy soil is the southern foot hills of the Western Ghats in south western India, Southeast Asia, Africa, South America, and Arabia. It has some common names such as Moringa, drumstick tree, horseradish tree and etc. [24]. Its young seed pods and leaves are used as vegetables, and many parts of the tree are used in traditional herbal medicine. It can also be used for water purification and hand washing [25]. Literature reported that Moringa oil has good potential for biodiesel production based on a recent survey conducted on indigenous plants derived non-traditional oils [26].

The Moringa Oleifera biodiesel was produced from raw Moringa Oleifera oil by two step tranesterification process (acid-base catalyst) in Annamalai University Laboratory, Chidambaram, India and the oil was purchased from there. The MOME was mixed with diesel at 25% by volume and the mixture was stirred by a magnetic stirrer for proper mixing of the blends. The physical and chemical properties of Moringa Oleifera methyl ester were tested and compared with the ASTM D6751 standards. The physico-chemical properties of diesel, characteristics of and Moringa Oleifera

methyl esters and its 25%by volume blends (MOME25) are given in Table 1.

Table 1: Fuel Properties

Properties	Diesel	Mome
Specific gravity	0.83	0.88
Kinematic Viscosity @ 40^{o}C (cSt)	3.9	5.18
Calorific value (MJ/kg)	43	36.4
Density (kg/m^3)	830	880
Flash point (^{o}C)	50	70
Fire point (^{o}C)	60	83
Cetane Number	48	52
Oxygen content (%) by weight	-	11

TEST ENGINE

In this present study, a VCR constant speed water cooled Kirloskar TV 1 model direct injection diesel engine with computerized engine management system was used. The test engine specifications are given in Table 2, and the schematic of experimental setup is shown in Figure 1. All the experiments were conducted by varying the engine brake load and running and constant speed. The engine was coupled with eddy current dynamometer.

Table 2: Specification Details of Test Engine

Engine type	TV1, 4S, Diesel engine
Power (kW)	5.2 kW
Bore x Stroke	87.5mmx110mm
Compression ratio	17.5:1
Displacement volume (cc)	661
Injection pressure	200bar
Injection timing	23^{o}bTDC
Speed	1500rpm
Type of cooling	Water cooled

A K type thermocouple was employed for measuring the cooling water, exhaust gas, and engine oil and inlet temperatures. The exhaust emissions were measured by AVL 444 gas analyzer and the smoke opacity was measured with AVL-437 smoke meter. The details of AVL gas analyzer and Smoke meter are shown in Table 3. The engine was running fuel by diesel for at least 10 min to warm up and taken the reading for base line data for comparison. Errors and uncertainties in of the instruments can arise from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainty analysis is used to determine the accuracy of experiments. The measurement accuracy and the uncertainty of different parameters, including BP, BSFC, CO, HC, NO, Smoke and CO2 emissions are given in Table 3.

Table 3: Uncertainty of Measured Parameters

Parameters	Speed	Load	Crank angle	Pressure	BTE	BSFC	CO	HC	NO	Smoke
Uncertainty,%	±0.5	±0.1	±0.1	±0.1	±0.05	±0.05	±0.1	±0.1	±0.2	±0.2

RESULTS AND DISCUSSIONS

In this study, engine performance characteristics are evaluated in terms of BTE and the BSFC and the emissions and combustion parameters were measured and compared with diesel and discussed in this section.

Performance Characteristics

The trend of BTE with brake power for diesel and MOME25 at different NOPs is shown in Figure 2. The BTE and BSFC were considered as the most important parameters for determination of performance for any engine (Subramani et al. 2018). The BTE of the MOME25 blend and diesel increased with increase in load together with diesel. However, the BTE of the MOME25 blend was lower than that of diesel fuel throughout the load range. This may be attributed to the reduction of calorific value, high viscosity and increased fuel consumption of biodiesel blend as compared to neat diesel. Further the BTE was increased with an increase in NOPs at all loads. The BTE of MOME25 at 240bar injection pressure obtained more values compared with other injection pressure and followed by MOME25 at 220bar and 260bar at full load. The increase in BTE may be due to more atomization and vaporization of biodiesel particles and excess oxygen in the biodiesel, resulting in complete combustion of biodiesel blend. At higher NOP of 260bar obtained the lower value of BTE when compared to MOME25 with 240bar, 220bar and 200bar due to lower momentum of fuel particle unable to move from the bottom of the combustion chamber and more accumulation of fuel injected at higher injection pressure leads to poor combustion. The BTE of MOME25 at 220bar, 240bar and 260bar are 28.48%, 30.16% and 28.84% respectively, whereas for diesel and MOME25 at standard injection pressure of 200bar is 29.7% and 27.82% respectively at full load.

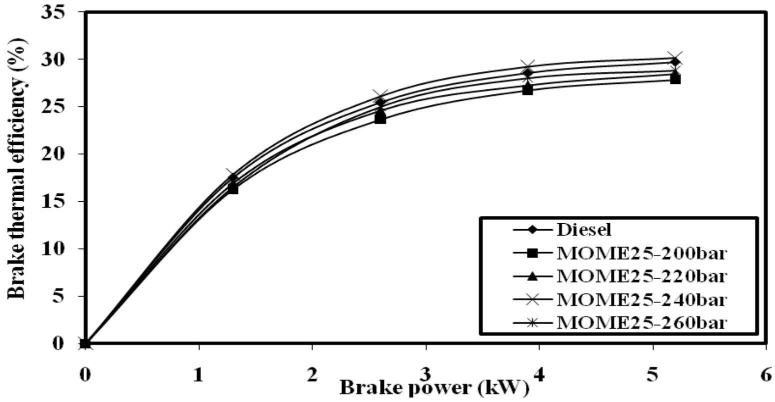

Figure 2: Variations of Brake Thermal Efficiency with BP

Figure 3 illustrates the variation in the BSEC with BP for diesel and MOME25 at different NOPs. The BSEC is calculated as the multiplication of BSFC and calorific value of the fuel. The BSEC of MOME25 is higher that of neat diesel fuel. This is due to the factors such as the fuel density, viscosity, and lower heating value of the biodiesel and these will affect the BSEC of diesel engines (Qi et al., 2010). The BSEC of MOME25 at 240bar injection pressure was lower when compared with other injection pressure and followed by MOME25 at 220bar and 260bar at full load. The BSEC obtained for the MOME25 with 200, 220, 240 and 260bar are 12.2MJ/kWh, 11.9MJ/kWh, 11.5MJ/kWh and 12.6MJ/kWh respectively and for diesel it is 11.2MJ/kWh at maximum load. The BSEC of MOME25 with 240bar NOP is 3.5% and 6.1% and 9.5%lowered with 200,220, and 260bar respectively. The decrease in BSEC of MOME25 with 240bar NOP is attributed to better atomization, vaporization and better penetration of fuel into the air at higher NOP which leads to better combustion and thus decreased BSEC at full load. This observation is similar with the results reported in the literature (Kalam et al., 2011; Chauhan et al., 2012; Wang et al., 2013).

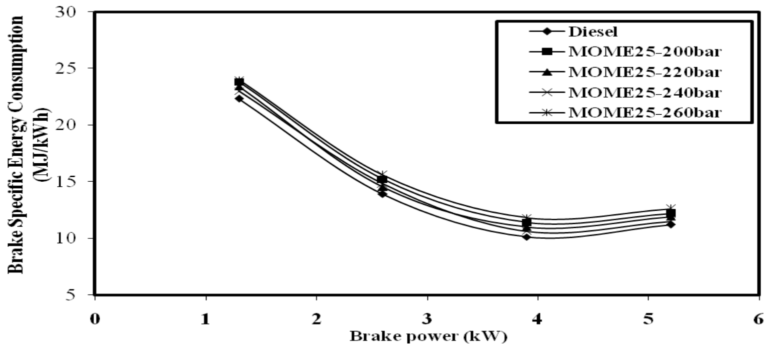

Figure 3: Brake Specific Fuel Consumption (BSFC) Versus BP

Exhaust gas temperature variations with BP for diesel and MOME25 at various NOPs are illustrated in Figure 4. The figure shows that when the load of the engine increases, the EGT increases due to more energy released from the fuel. More heat is generated when the more mass of fuel is being injected at higher loads during the combustion process (Heywood 1988). In addition, combustion process is improved for increase in NOPs, due to better atomization and better vaporization of fuel, leading to complete combustion and thus increases the EGT compared with MOME25 at standard NOP. Higher EGT was obtained for MOME25 may be due to better combustion of MOME25 as compared to MOME25 at 200bar. The EGT obtained diesel and MOME25 are 364oC and 386oC respectively, and for 220bar, 240bar and 20bar NOPs, it is 416oC, 426oC, 395oC respectively.

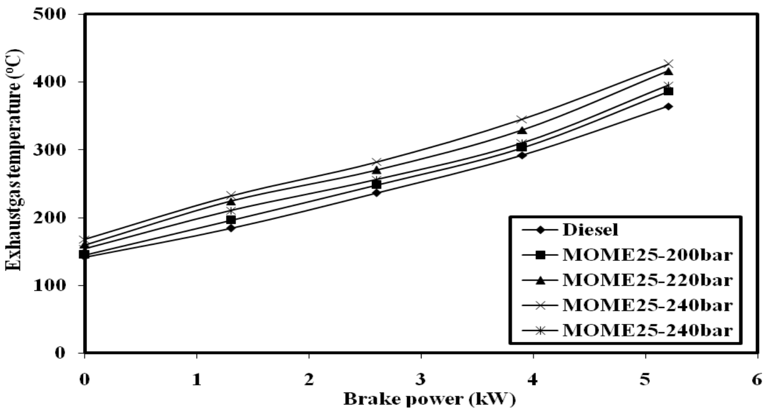

Figure 4: Exhaust Gas Temperature Versus BP

Emission Characteristics

The variation in CO emissions with BP for diesel and MOME25 at different NOPs is presented in Figure 5. The CO emissions are produced due to incomplete combustion of fuel and insufficient molecular oxygen content present in the fuel. In general, air-fuel ratio, engine speed, and type of fuel which affects CO emissions (Gumus et al., 2012). The CO emission decreases with increase in injection pressure for MOME25 biodiesel blend at maximum load conditions. The CO emission lowered with increase in injection pressures for B25 except 260bar NOP with maximum load. The maximum CO emissions obtained for MOME25 with 200 bar, 220 bar, 240bar and 260 bar NOPs are 0.125 %, 0.11 %, 0.09 % and 0.135 % respectively, and it is 0.14% for diesel at maximum load. The CO emission for MOME25 biodiesel with 240bar is decreased by 38%, 22% and 50% for 200bar, 220bar and 260bar respectively at maximum load conditions. The reason may be due to better atomization and vaporization of fuel at higher NOP, and more oxygen molecules present in biodiesel and

higher cetane number of biodiesel resulting in better combustion at full load.

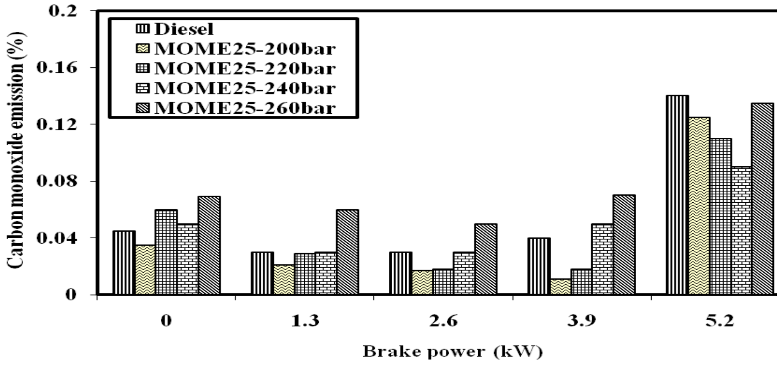

Figure 5: Variation in CO Emissions with BP

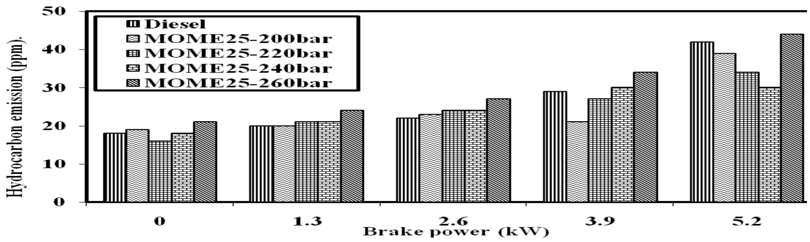

Figure 6: Variation in HC Emissions with BP

The variation in HC emissions with BP for diesel and MOME25 fuels at different NOPs are shown in Figure 6. Unburned HC emission is produced as a result of incomplete combustion of fuels and flame quenching on the cylinder walls [Heywood, 1998]. The HC emission for MOME25 at 200bar NOP is lower than neat diesel fuel at full load due to its excess molecular oxygen present in the biodiesel which promotes oxidation of MOME25. At maximum load, HC emissions for MOME25 at 220bar, 240bar and 260bar NOP are 34ppm,30ppm and 44ppm respectively. The HC emission is lowered for MOME25 with 240bar NOP due to better atomization, vaporization of fuel particles and more oxygen molecules present in the biodiesel and higher cetane number of biodiesel, which promotes the complete combustion of MOME25 (Lin et al., 2009; Qi et al., 2010b). The HC emission for MOME25 with 240bar NOP decreased by 28% compared to diesel and about 23% and 11% lowered by 200bar and 220bar respectively. At NOP 260bar, the HC emission for MOME is increased by 13% when compared to MOME25 at standard NOP 200bar at full load due to more fuel injected at high NOP and the fine fuel droplets are unable to move in the combustion chamber resulting in incomplete combustion. Thus HC emissions are increased compared with other NOPs.

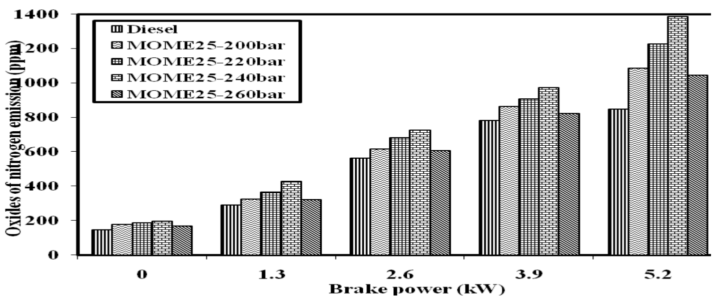

Figure 7: Variation of NOx Emissions with BP

The variation in the NOx emissions with BP for the diesel and MOME25 at various NOPs are illustrated in Figure 7. The NOx values were higher for the MOME25 compared to diesel fuel. In general, the biodiesel blend produced higher NO emissions and it may be attributed to the higher adiabatic flame temperature of the biodiesel blend and it also due to that the biodiesel contains more unsaturated fatty acids, results in higher adiabatic flame temperatures, which cause higher NO emissions (El-Kasaby and Nemit-allah, 2013). The maximum NOx emissions produced for MOME25 with 220bar, 240bar and 260bar is increased by 13% and 28% respectively compared to MOME25 at 200bar injection pressure. This result can be attributed to the leaner air/fuel ratio and better atomization of MOME25 and it is an oxygenated fuel that contains 12% more molecular oxygen than diesel—which increases the combustion chamber temperature and thus improved combustion process (Devan and Mahalakshmi (2009). Thus, NO emissions were higher for the MOME 25 than neat diesel fuel. This result is consistent with other researchers (El-Kasaby and Nemit-allah, 2013).

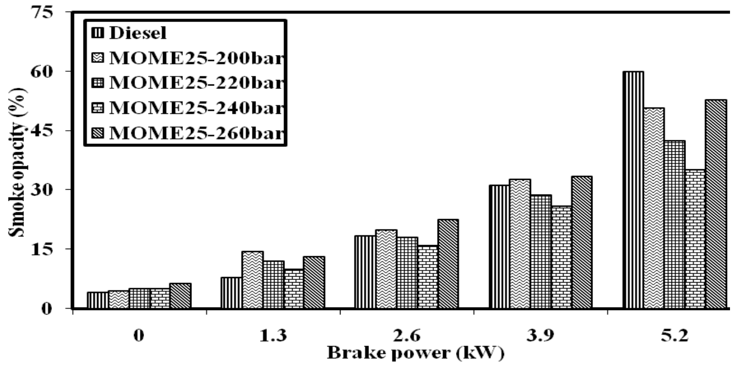

Figure 8: Variation of Smoke Opacity with BP

Figure 8 shows the variation of smoke opacity with brake power for diesel and MOME25 with different NOPs. Smoke emission produced in diesel engine due to physical and chemical properties of fuel and nature of combustion process. The oxygen content in the biodiesel plays a vital role in smoke emission in diesel engine. At full load, smoke emission was observed for diesel and MOME25 at 200bar NOP is 59.9% and 50.8% respectively. The smoke emission for B25 with 220bar, 240bar and 260bar is 42.5%, 35.2% and 52.8% respectively at full load. This reduction smoke emission for blends with 220bar and 240bar may be attributed to better atomization and vaporization of biodiesel blend at higher NOPs and the presence of more oxygen molecule (12% by wt) present in the biodiesel, which enhanced the combustion process and results in lower smoke opacity than diesel. The smoke emission for B25 with 220bar and 240bar by 16.5% and 31% respectively compared with blends at 200bar NOP at full load. was decreased by At higher injection pressure 260bar the smoke emission was increased due more fine particle of biodiesel blend was unable to mix with air due to its loss momentum and more quantity of fuel was injected at higher injection pressure.

Combustion Characteristics

Figure 9 shows the variation of cylinder pressure with crank angle for MOME25 and neat diesel at different injection pressures. In-cylinder pressure was considered as the most important parameter to determine the combustion characteristics of any fuel. Cylinder pressure variations inside cylinder depend on the quantity of fuel injected into the cylinder and its quality. From the figure, it is noticed that the trend of in-cylinder pressure for both diesel and MOME25 follows the same trend for all injection pressures. The peak in-cylinder pressure of MOME25 is slightly lower than peak pressure for diesel. The peak cylinder pressure for diesel and MOME25 is 69.4 bar and 667bar respectively at standard

injection pressure of 200bar and for 220bar, 240bar and 260bar NOP it is 68.9bar, 70.4bar and 66.5bar respectively. The increase in in-cylinder pressure for MOME25 at 240bar pressure is due to better atomization and better mixing of fuel with air at higher injection pressure, resulting in better burning of fuel and air. At full load conditions the peak cylinder pressure for MOME25 increases with increase in injection pressure from 200bar to 240bar marginally. Higher fuel injection pressure beyond 240bar has no significant effect on peak cylinder pressure due to more quantity of fuel injected into the engine cylinder within a shorter duration resulting in poor in poor combustion (Akash Deep et al.2017).

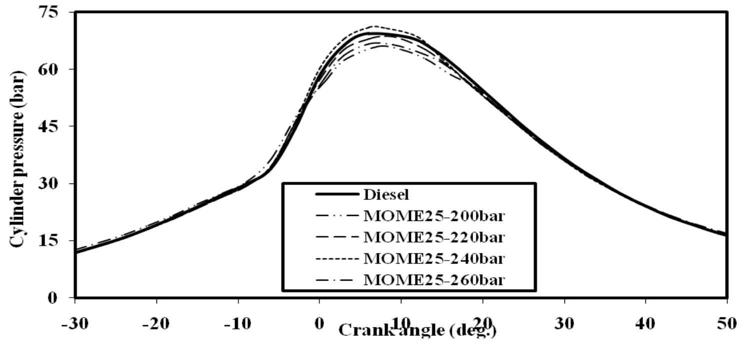

Figure 9: Variation in the Cylinder Pressure Crank Angle at Full Load

The variation in the rate of heat release with crank angle for diesel and MOME25at different injection pressures are demonstrated in Figure 10. It can be seen from the Figure that the trend of heat release rate of both fuels are the same trend. The heat release rate of diesel and MOME25 is 56J/^{o}CA and 57J/^{o}CA respectively at standard injection pressure and for 220bar, 240bat and 260bar it is 60J/^{o}CA, 64J/^{o}CA and 54J/^{o}CA respectively at full load. It is observed from the graph, the combustion starts early for MOME25 compared to diesel and this is due to higher Cetane number of biodiesel compared to the diesel as reported by many researchers. The shorter ignition delay, higher viscosity and surface tension of MOME25 may be attributed to the lower heat release rate of MOME25 compared to diesel. It s also be seen that the heat release of rate of MOME25 is maximum for 240bar injection pressure and thereafter it decreases considerably beyond 240 bar. This is because of poor combustion happening at 260 bar injection pressure at full load due to non homogeneity of fuel air mixture resulted from poor entrainment of air (Akash Deep et al.2017).

CONCLUSIONS

In this study, biodiesel was produced from raw Moringa oleifera oil and tested the fuel properties and compared with diesel fuel. The experimental test was conducted to study the combustion, performance and emission characteristic of diesel engine with 25% Moringa-diesel blend (MOME25) was evaluated. Based on the experimental test, the following conclusions were drawn;

Increase in NOPs increases the performance characteristics of the engine using MOME25 in terms of BSFC and BTE. The maximum performance is achieved at 240bar NOP and BSFC improved by 10% and BTE increased by 1.68% when compared to diesel at standard injection pressure and the EGT of MPME25 decreases with all nozzle opening pressures.

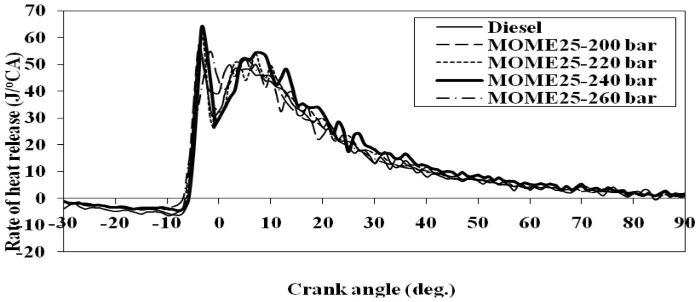

Figure 10: Variation in the Heat Release Rate with Crank Angle at Full Load

From the emission point of view, for MOME25 with an increase in NOPs leads to decrease in CO, UBHC, smoke emissions and also exhaust temperature. NO emissions were increased at higher NOPs because of higher combustion temperature when compared to diesel. MOME25 blend gave produced higher cylinder pressure at higher NOPs due to better combustion. Heat release rate was increased at 240bar NOP when contrasted with diesel.

Finally, it is concluded that the MOME25 blend at 240bar NOP gave superior performance and reduction in emissions when contrasted with diesel at standard injection pressure of 200bar. Finally it is concluded that Moringa Oleifera oil diesel blend is a potential feedstock for biodiesel production and the performances of MOME25 blends are comparable with diesel fuel. The exhaust gas emissions are drastically decreased at 240bar NOP when compared to diesel ant it can replace the diesel fuel in unmodified engines to reduce the global energy demand and environmental pollutions.

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